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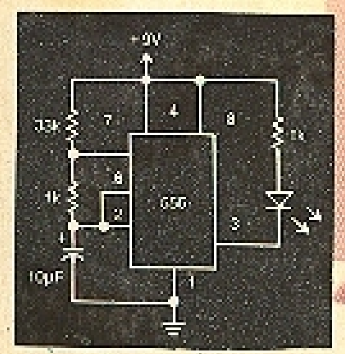
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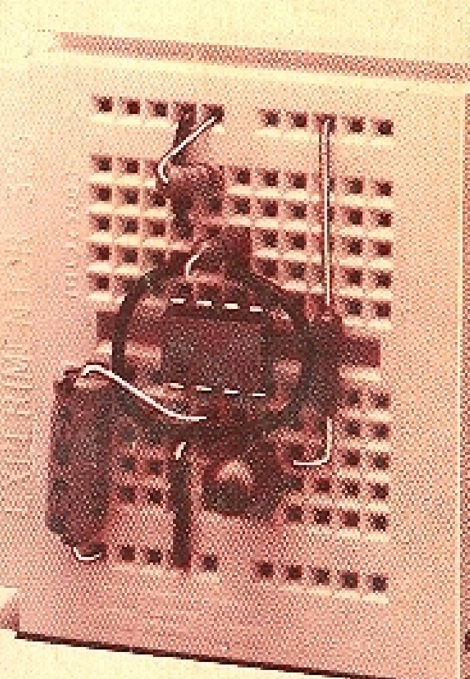
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Engineer's Mini-Notebook

Optoelectronics Circuits





Forrest M. Mims III

Radio Shack®

CIRCUIT SYMBOLS

FIXED RESISTOR
VARIABLE RESISTOR
FIXED CAPACITOR
POLARIZED CAPACITOR
RECTIFIER/ DIODE
ZENER DIODE
PNP TRANSISTOR
NPN TRANSISTOR
LED
SOLAR CELL
PHOTO-RESISTOR
PHOTO-TRANSISTOR
+V
CONNECTED WIRES
UNCONNECTED WIRES
POSITIVE SUPPLY
GROUND
SPST SWITCH
SPDT SWITCH
NORMALLY OPEN PUSHBUTTON
NORMALLY CLOSED PUSHBUTTON
RELAY
TRANSFORMER
SPEAKER
PIEZO-SPEAKER
METER
LAMP
BATTERY
OP-AMP

ENGINEER'S MINI-NOTEBOOK

OPTOELECTRONIC CIRCUITS

BY

FORREST M. MIMS, III

CONTRIBUTING EDITOR
MODERN ELECTRONICS

AUTHOR OF "SILICONNECTIONS — COMING OF AGE IN THE ELECTRONIC ERA"

FIRST EDITION

A SILICONCEPTS™ BOOK

PRINTED IN THE UNITED STATES OF AMERICA

THIS BOOK INCLUDES STANDARD APPLICATION CIRCUITS AND CIRCUITS DESIGNED BY THE AUTHOR. EACH CIRCUIT WAS ASSEMBLED AND TESTED BY THE AUTHOR AS THE BOOK WAS DEVELOPED. AFTER THE BOOK WAS COMPLETED, THE AUTHOR REASSEMBLED EACH CIRCUIT TO CHECK FOR ERRORS. WHILE REASONABLE CARE WAS EXERCISED IN THE PREPARATION OF THIS BOOK, VARIATIONS IN COMPONENT TOLERANCES AND CONSTRUCTION METHODS MAY CAUSE THE RESULTS YOU OBTAIN TO DIFFER FROM THOSE GIVEN HERE. THEREFORE THE AUTHOR AND RADIO SHACK ASSUME NO RESPONSIBILITY FOR THE SUITABILITY OF THIS BOOK'S CONTENTS FOR ANY APPLICATION. SINCE WE HAVE NO CONTROL OVER THE USE TO WHICH THE INFORMATION IN THIS BOOK IS PUT, WE ASSUME NO LIABILITY FOR ANY DAMAGES RESULTING FROM ITS USE. OF COURSE IT IS YOUR RESPONSIBILITY TO DETERMINE IF COMMERCIAL USE, SALE OR MANUFACTURE OF ANY DEVICE THAT INCORPORATES INFORMATION IN THIS BOOK INFRINGES ANY PATENTS, COPYRIGHTS OR OTHER RIGHTS.

DUE TO THE MANY INQUIRIES RECEIVED BY RADIO SHACK AND THE AUTHOR, IT IS NOT POSSIBLE TO PROVIDE PERSONAL RESPONSES TO REQUESTS FOR ADDITIONAL INFORMATION (CUSTOM CIRCUIT DESIGN, TECHNICAL ADVICE, TROUBLESHOOTING ADVICE, ETC.). IF YOU WISH TO LEARN MORE ABOUT ELECTRONICS, SEE OTHER BOOKS IN THIS SERIES AND RADIO SHACK'S "GETTING STARTED IN ELECTRONICS." ALSO, READ MAGAZINES LIKE *MODERN ELECTRONICS* AND *RADIO-ELECTRONICS*. THE AUTHOR WRITES A MONTHLY COLUMN, "ELECTRONICS NOTEBOOK," FOR *MODERN ELECTRONICS*.

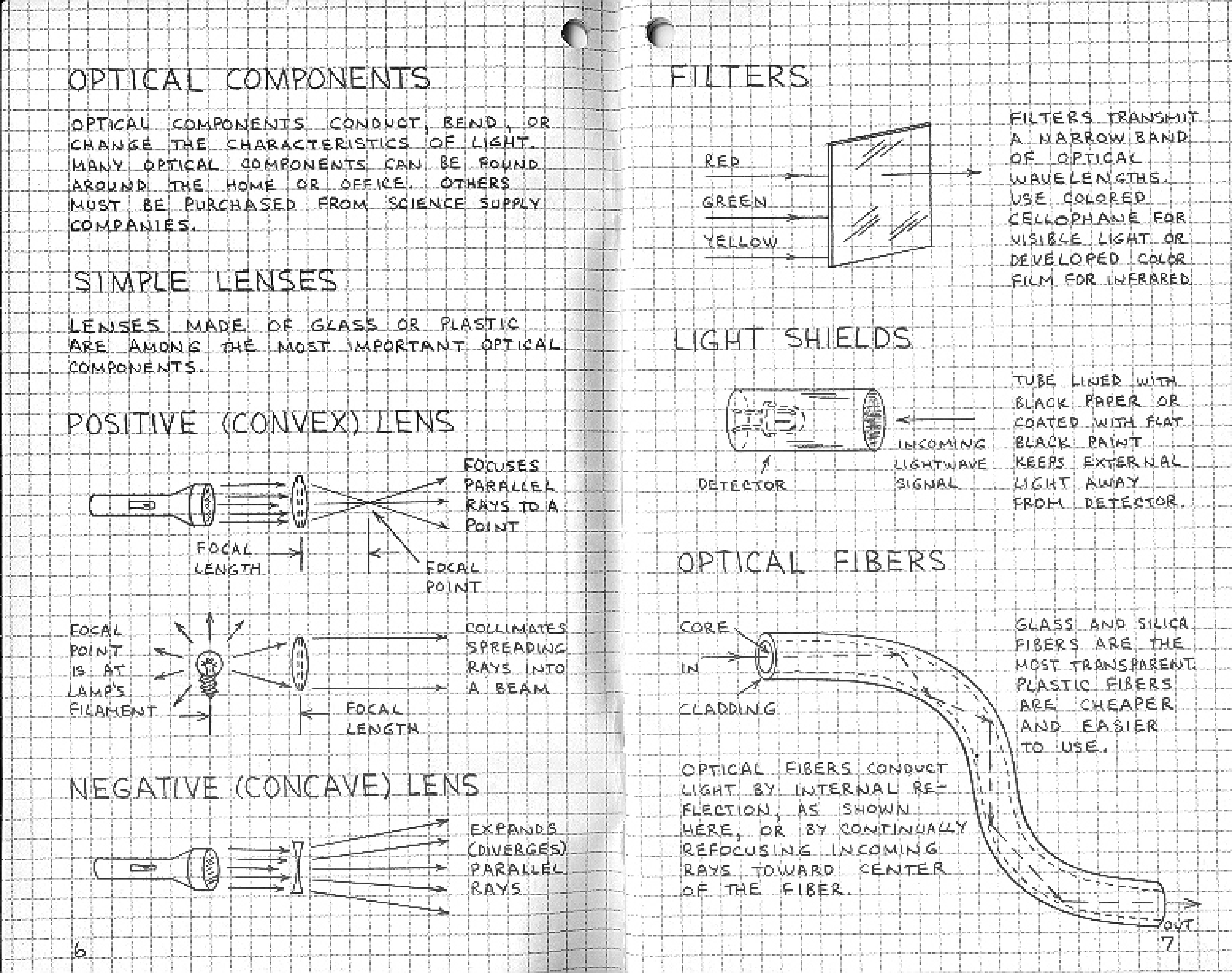
CONTENTS

INTRODUCTION

OPTOELECTRONICS IS THE TERM FOR THE COMBINED TECHNOLOGIES OF OPTICS AND ELECTRONICS. ELECTRONIC DEVICES THAT EMIT OR DETECT OPTICAL RADIATION ARE CALLED OPTOELECTRONIC COMPONENTS. OPTOELECTRONIC CIRCUITS HAVE WIDESPREAD APPLICATIONS IN COMMUNICATIONS, SENSING, CONTROL, AND READOUTS. MANY KINDS OF SOLID-STATE OPTOELECTRONIC COMPONENTS ARE AVAILABLE AT REASONABLE PRICES FROM RADIO SHACK. SO IS "GETTING STARTED IN ELECTRONICS," A BOOK THAT WILL HELP YOU ASSEMBLE THE CIRCUITS IN THIS BOOK.

THE OPTICAL SPECTRUM

nm = NANOMETER (1 nm = .000 000 001 METER)
μ = MICROMETER (1 μ = .000 001 METER)
mm = MILLIMETER (1 mm = .001 METER)



OPTICAL COMPONENTS

OPTICAL COMPONENTS CONDUCT, BEND, OR CHANGE THE CHARACTERISTICS OF LIGHT. MANY OPTICAL COMPONENTS CAN BE FOUND AROUND THE HOME OR OFFICE. OTHERS MUST BE PURCHASED FROM SCIENCE SUPPLY COMPANIES.

SIMPLE LENSES

LENSES MADE OF GLASS OR PLASTIC ARE AMONG THE MOST IMPORTANT OPTICAL COMPONENTS.

POSITIVE (CONVEX) LENS

NEGATIVE (CONCAVE) LENS

FILTERS

FILTERS TRANSMIT A NARROW BAND OF OPTICAL WAVELENGTHS. USE COLORED CELLOPHANE FOR VISIBLE LIGHT OR DEVELOPED COLOR FILM FOR INFRARED.

LIGHT SHIELDS

TUBE LINED WITH BLACK PAPER OR COATED WITH FLAT BLACK PAINT KEEPS EXTERNAL LIGHT AWAY FROM DETECTOR.

OPTICAL FIBERS

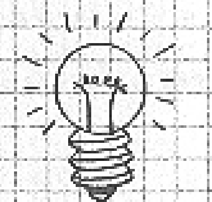
GLASS AND SILICA FIBERS ARE THE MOST TRANSPARENT. PLASTIC FIBERS ARE CHEAPER AND EASIER TO USE.

OPTICAL FIBERS CONDUCT LIGHT BY INTERNAL RE-FLECTION, AS SHOWN HERE, OR BY CONTINUALLY REFOCUSING INCOMING RAYS TOWARD CENTER OF THE FIBER.

LIGHT SOURCES

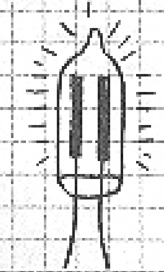
MANY LIGHT SOURCES ARE AVAILABLE FOR OPTOELECTRONIC PROJECTS. THE MOST IMPORTANT SOURCES INCLUDE:

INCANDESCENT LAMPS



AN INCANDESCENT LAMP IS MADE BY ENCLOSING A THIN TUNGSTEN WIRE (THE FILAMENT) IN AN EVACUATED GLASS ENVELOPE. AN ELECTRICAL CURRENT PASSED THROUGH THE FILAMENT CAUSES IT TO BECOME INCANDESCENT (WHITE HOT). THE OPERATING LIFE AND BRILLIANCE OF AN INCANDESCENT LAMP CAN BE INCREASED BY FILLING THE ENVELOPE WITH A GAS SUCH AS ARGON, NITROGEN, OR KRYPTON. THE ULTRA-BRIGHT HALOGEN LAMP HAS A QUARTZ ENVELOPE FILLED WITH A HALOGEN GAS LIKE IODINE OR BROMINE. THE GAS COMBINES WITH TUNGSTEN ON THE ENVELOPE WALL AND DEPOSITS IT ON THE FILAMENT.

GAS-DISCHARGE LAMPS

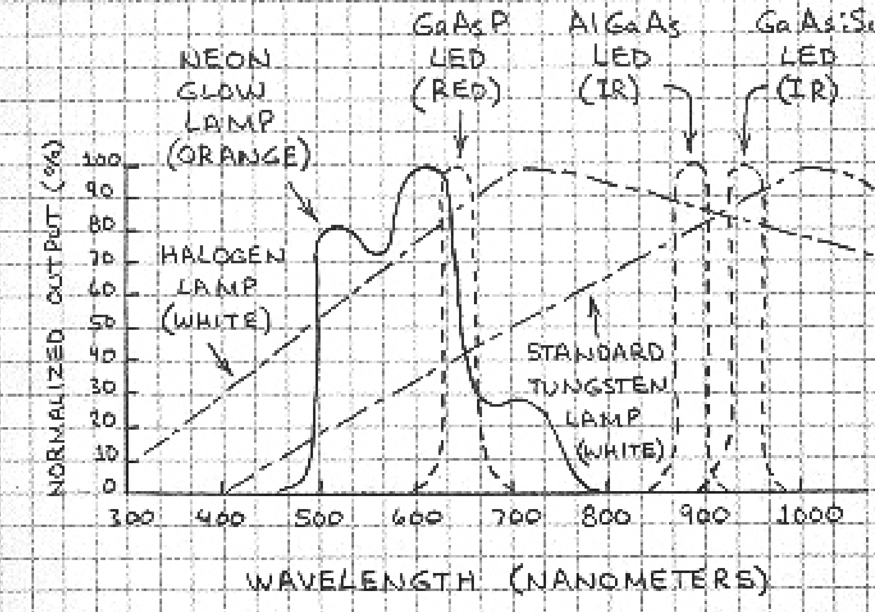


THE SIMPLEST GAS-DISCHARGE LAMP, THE NEON GLOW LAMP, IS A GLASS ENVELOPE FILLED WITH NEON GAS. WHEN THE VOLTAGE ACROSS TWO ELECTRODES IN THE ENVELOPE EXCEEDS 60-70 VOLTS, THE IONIZATION OR BREAKDOWN VOLTAGE OF NEON, AN ELECTRICAL DISCHARGE IS ESTABLISHED BETWEEN THE ELECTRODES, AND THE NEON EMITS AN ORANGE GLOW. OTHER GAS-DISCHARGE LAMPS ARE THE XENON FLASH LAMP AND THE MERCURY VAPOR LAMP.

LIGHT-EMITTING DIODES

THE LIGHT-EMITTING DIODE (LED) IS A SEMICONDUCTOR PN JUNCTION DIODE THAT EMITS VISIBLE LIGHT OR NEAR-INFRARED RADIATION WHEN FORWARD BIASED. VISIBLE LEDs EMIT RELATIVELY NARROW BANDS OF GREEN, YELLOW, ORANGE, OR RED LIGHT. INFRARED DIODES EMIT IN ONE OF SEVERAL BANDS JUST BEYOND RED LIGHT. LEDs SWITCH OFF AND ON RAPIDLY, ARE VERY EFFICIENT, HAVE A VERY LONG LIFETIME, AND ARE EASY TO USE. LEDs ARE CURRENT DEPENDENT SOURCES, AND THEIR LIGHT OUTPUT IS DIRECTLY PROPORTIONAL TO THE FORWARD CURRENT.

LIGHT SOURCE SPECTRA



HOW TO USE LEDs

LIGHT-EMITTING DIODES ARE VERY RUGGED, LONG-LIVED OPTICAL SOURCES. THE LIGHT THEY EMIT HAS AN INTENSITY THAT IS LINEAR WITH RESPECT TO THE FORWARD CURRENT THROUGH THE LED. TO PREVENT IRREVERSIBLE DAMAGE, ALWAYS OPERATE AN LED WITHIN ITS RATINGS.

FLAT SPOT
SHORT LEAD
CATHODE
EPOXY
ANODE

ANODE
CATHODE
LED SYMBOL

USE A SERIES RESISTOR (R_S) TO LIMIT THE CURRENT THROUGH AN LED TO A SAFE VALUE.

$+V_{IN}$
R_S
LED

USE THIS FORMULA TO DETERMINE THE RESISTANCE OF R_S:

$$R_S = \frac{V_{IN} - V_{LED}}{I_{LED}}$$

I_{LED} IS THE SPECIFIED FORWARD CURRENT.

V_{LED} IS THE LED VOLTAGE DROP. IT RANGES FROM ABOUT 1.3 VOLTS (940 nm INFRARED EMITTERS) TO ABOUT 2.5 VOLTS (GREEN EMITTERS).

SAMPLE LED CIRCUIT

B1
6V
R_S
RED LED
V_{LED} = 1.7V
I_{LED} = 20 mA

$$R_S = \frac{6 - 1.7}{.02} = 215 \text{ OHMS}$$

220 Ω IS CLOSEST STANDARD VALUE.

LOGIC CIRCUIT LED DRIVERS

TTL:

IN
+5V
R_S
LED
ENABLE (WHEN HIGH)
R_S = 220 Ω
I_{LED} = 15 mA

TTL OR CMOS:

A SIMPLE BUT EFFECTIVE LOGIC PROBE CAN BE MADE FROM THIS CIRCUIT. APPLY INPUT SIGNAL

+5V
R_S = 220 Ω
Q1
2N2222
IN
R1
10K
ENABLE (WHEN HIGH)
LED
I_{LED} = 15 mA

VALUES OF R_S ARE FOR TYPICAL RED LEDs.

AC/DC POLARITY INDICATOR

V R_S LED 1   LED 2

V	LED 1	LED 2
+	ON	OFF
−	OFF	ON
AC	ON	ON

VOLTAGE-LEVEL INDICATOR

+V R_S D1   LED

D1 IS A ZENER DIODE.

LED WILL GLOW WHEN +V EXCEEDS THE BREAKDOWN VOLTAGE OF THE ZENER DIODE. NOTE THAT D1 IS REVERSE BIASED.

LED BRIGHTNESS CONTROL

+V   R1 R_S LED

SELECT R_S AS IF R1 NOT PRESENT.

R1 1K (ADJUST TO ALTER LED BRIGHTNESS.)

LOGIC PROBE

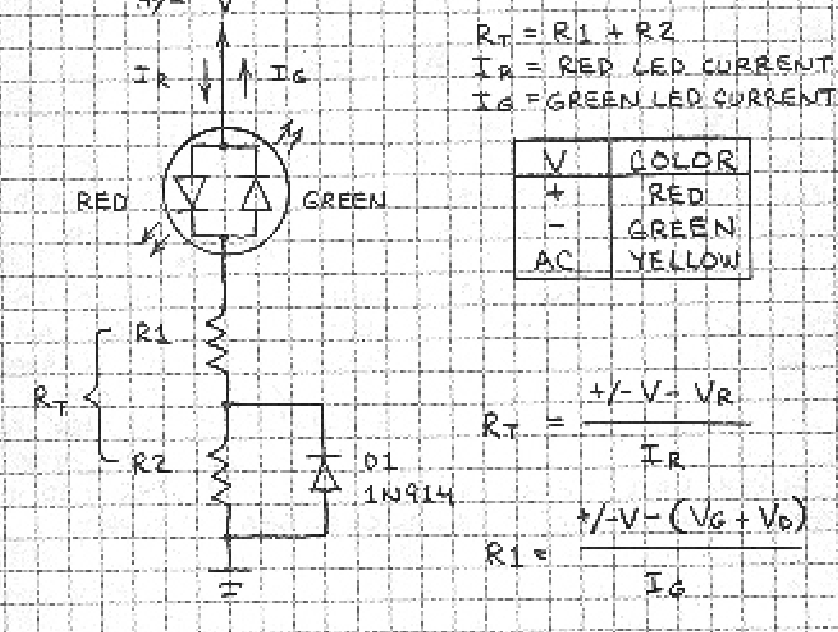
+5   R2 220   Q1 2N2222   R1 100K   IN   Q2 2N2222   LED

USE THIS PROBE TO MONITOR THE LOGICAL STATUS OF LOGIC GATES.

IN	LED
HIGH	ON
LOW	OFF

HOW TO USE TRI-COLOR LEDs

TRI-COLOR LEDs ARE MADE BY INSTALLING A RED AND GREEN LED CHIP IN THE SAME PACKAGE. THE TWO CHIPS ARE USUALLY CONNECTED IN REVERSE-PARALLEL.



V	COLOR
+	RED
−	GREEN
AC	YELLOW

V_R = RED LED FORWARD VOLTAGE (ABOUT 2 V)
V_G = GREEN LED FORWARD VOLTAGE (ABOUT 2 V)
V_D = D1 FORWARD VOLTAGE (0.6 V).

SAMPLE CALCULATION:

ASSUME +/- V = 5 VOLTS AND I_R & I_G = 20 MILLIAMPERES.

$R_T = \frac{5-2}{.02}$ = 150 OHMS $R1 = \frac{5-(2+.6)}{.02}$ = 120 OHMS

$R2 = R_T - R1$ = 30 OHMS   SELECT STANDARD RESISTANCE VALUES CLOSEST TO THESE.

HOW TO USE FLASHER LEDs

FLASHER LEDs INCLUDE IN THE LED PACKAGE A MINIATURE INTEGRATED CIRCUIT THAT CAUSES THE LED TO FLASH FROM 2 TO 6 TIMES EACH SECOND. CAN BE USED WITHOUT A SERIES RESISTOR.

BASIC LED FLASHERS

+3 TO +7 V

NO SERIES RESISTOR

FLASHER LED

+3 TO +7V

STANDARD LED

BOTH LEDs FLASH

UP TO 60 LEDs CAN BE FLASHED BY COX21 FLASHER LED. ADD 1.09 V PER LED TO SUPPLY.

FLASH RATE DECREASES AS FORWARD VOLTAGE INCREASES.

+V

FLASHER LED

D1

D1 = 5.6 TO 6V

USE THIS CIRCUIT WHEN VOLTAGE EXCEEDS SAFE VALUE. D1 IS A ZENER DIODE.

+5V

FLASHER LED

IN

HOW TO DRIVE FLASHER LED FROM A TTL GATE. THIS WILL WORK WITH HIGH-OUTPUT CMOS.

DUAL LED FLASHER

FLASHER LED

+6 V

R2 220

Q1 2N2222

LED

R1 47

WHEN THE SUPPLY VOLTAGE IS 6 VOLTS, THE LEDs WILL FLASH ALTERNATELY. THE STANDARD LED WILL REMAIN ON WHEN THE SUPPLY VOLTAGE FALLS BELOW 6 VOLTS.

POWER FLASHER

+9 V

LED

FLASHER LED

THIS CIRCUIT WILL PERMIT A LOW-CURRENT LED FLASHER TO SWITCH A RELAY OFF AND ON. USE SEPARATE POWER SUPPLIES FOR RELIABLE OPERATION.

6 VOLT LAMP

Q1 2N2222

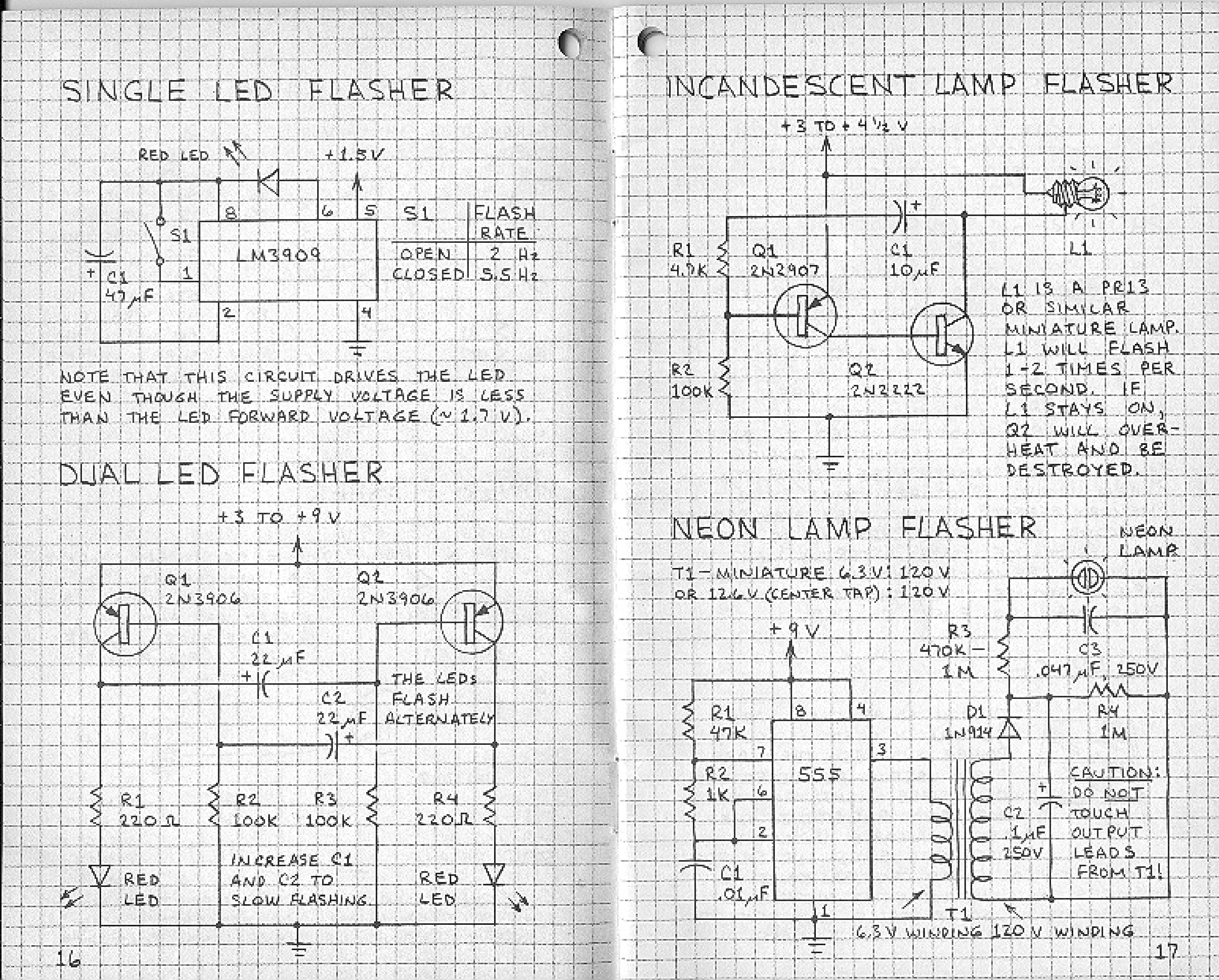
B1 6V

RY1

LED IS INCLUDED TO REDUCE VOLTAGE TO FLASHER.

RY1 — USE A 6-9 VOLT DC, 500 Ω RELAY.

CAUTION: DO NOT USE THIS CIRCUIT TO FLASH LINE-POWERED LAMPS. DO NOT EXCEED THE CURRENT RATING OF THE RELAY'S CONTACTS.


SINGLE LED FLASHER
RED LED
+1.5V
S1
C1
47 µF
LM3909
S1 | FLASH RATE
OPEN | 2 Hz
CLOSED | 5.5 Hz
NOTE THAT THIS CIRCUIT DRIVES THE LED EVEN THOUGH THE SUPPLY VOLTAGE IS LESS THAN THE LED FORWARD VOLTAGE (~1.7 V).
DUAL LED FLASHER
+3 TO +9 V
Q1
2N3906
Q2
2N3906
C1
22 µF
C2
22 µF
THE LEDs FLASH ALTERNATELY
R1
220 Ω
R2
100K
R3
100K
R4
220 Ω
RED LED
INCREASE C1 AND C2 TO SLOW FLASHING.
RED LED
16
INCANDESCENT LAMP FLASHER
+3 TO +4 ½ V
R1
4.7K
Q1
2N2907
C1
10 µF
L1
R2
100K
Q2
2N2222
L1 IS A PR13 OR SIMILAR MINIATURE LAMP. L1 WILL FLASH 1-2 TIMES PER SECOND. IF L1 STAYS ON, Q2 WILL OVERHEAT AND BE DESTROYED.
NEON LAMP FLASHER
NEON LAMP
T1 – MINIATURE 6.3V : 120 V OR 12.6 V (CENTER TAP) : 120 V
+9 V
R3
470K – 1M
C3
.047 µF, 250V
R1
47K
R2
1K
555
D1
1N914
R4
1M
C1
.01 µF
C2
.1 µF
250V
CAUTION: DO NOT TOUCH OUTPUT LEADS FROM T1!
T1
6.3 V WINDING 120 V WINDING
17

LIGHT SENSORS

MANY LIGHT SENSORS ARE AVAILABLE FOR OPTOELECTRONIC PROJECTS. THE MOST COMMONLY USED SENSORS INCLUDE:

PHOTORESISTORS

THE ELECTRICAL RESISTANCE OF A DARK PHOTORESISTOR IS ORDINARILY VERY HIGH, UP TO 1,000,000 OHMS OR MORE. THE RESISTANCE MAY FALL TO AS LITTLE AS A FEW HUNDRED OHMS WHEN THE PHOTORESISTOR IS ILLUMINATED. THE MOST COMMON SEMICONDUCTOR USED TO MAKE PHOTORESISTORS IS CADMIUM SULFIDE (CdS). IT IS PRIMARILY SENSITIVE TO GREEN LIGHT. PHOTORESISTORS EXHIBIT A "MEMORY EFFECT" IN THAT THEY MAY REQUIRE A SECOND OR MORE TO RETURN TO THEIR HIGH-RESISTANCE STATE AFTER A LIGHT SOURCE IS REMOVED. THOUGH THIS SLOWS THEIR RESPONSE TIME, THEY ARE VERY SENSITIVE AND EASY TO USE.

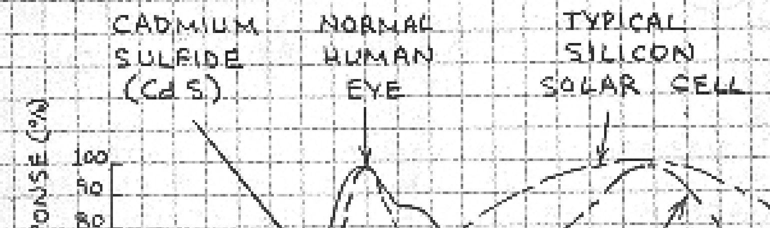
SOLAR CELLS

THOUGH SOLAR CELLS ARE GENERALLY USED IN SOLAR POWER SUPPLIES, THEY ARE ALSO USEFUL AS DETECTORS OF VISIBLE LIGHT AND NEAR-INFRARED RADIATION. THEY ARE AVAILABLE IN MANY DIFFERENT SIZES AND SHAPES. SINCE A TYPICAL SOLAR CELL RESPONDS TO CHANGES IN LIGHT INTENSITY WITHIN 20 MICROSECONDS, SOLAR CELLS CAN DETECT VOICE MODULATED LIGHTWAVE SIGNALS.

PHOTOTRANSISTORS

ALL TRANSISTORS ARE LIGHT SENSITIVE. PHOTOTRANSISTORS ARE DESIGNED TO EXPLOIT THIS PHENOMENON. THOUGH A BIPOLAR TRANSISTOR HAS THREE LEADS, A PHOTOTRANSISTOR MAY NOT HAVE A BASE LEAD. MOST PHOTOTRANSISTORS ARE NPN DEVICES WITH A BASE REGION MUCH LARGER THAN THAT OF A STANDARD NPN TRANSISTOR. THEY HAVE A RESPONSE TIME OF 1 MICROSECOND IN SOME CIRCUITS. THE DARLINGTON PHOTO-TRANSISTOR INCLUDES A SECOND ON-CHIP TRANSISTOR TO AMPLIFY THE SIGNAL GENERATED BY THE PHOTOTRANSISTOR. IT GIVES MORE SENSITIVITY BUT IS SLOWER.

SENSOR SPECTRAL RESPONSE



HOW TO USE LIGHT DETECTORS

LIGHT DETECTORS CAN BE OPERATED IN ONE OR MORE OF THESE MODES:

1. PHOTORESISTIVE – THE RESISTANCE OF THE DETECTOR VARIES WITH THE LIGHT LEVEL.

2. PHOTOVOLTAIC – THE DETECTOR GENERATES A CURRENT WHEN ILLUMINATED.

3. PHOTOCONDUCTIVE – THE DETECTOR ALLOWS CURRENT FROM AN EXTERNAL POWER SUPPLY TO FLOW IN RESPONSE TO LIGHT.

PHOTORESISTORS

SYMBOL

PHOTORESISTORS ARE PHOTORESISTIVE DETECTORS. THEY CAN OFTEN BE SUBSTITUTED FOR FIXED OR VARIABLE RESISTORS TO MAKE AN EXISTING CIRCUIT SENSITIVE TO LIGHT.

THE VARIABLE RESISTANCE OF A PHOTORESISTOR CAN BE CHANGED TO A VARIABLE VOLTAGE BY MEANS OF A SIMPLE VOLTAGE DIVIDER CIRCUIT.

VIN R1 VOUT R2

$$V_{OUT} = V_{IN}\left(\frac{R2}{R1+R2}\right)$$

VIN VOUT VOUT LIGHT IN

VIN VOUT VOUT LIGHT IN

SOLAR CELLS

OR

SYMBOLS

SOLAR CELLS ARE PRIMARILY PHOTOVOLTAIC DEVICES, BUT THEY ARE SOMETIMES USED IN A PHOTOCONDUCTIVE MODE. USE THEM TO POWER A CIRCUIT OR SENSE LIGHT.

SOLAR CELLS MAY BE SUPPLIED WITH OR WITHOUT LEADS. THOUGH SOLAR CELLS ARE FRAGILE, IT IS RELATIVELY EASY TO SOLDER WIRE LEADS TO THEM. USE A LOW-WATTAGE SOLDERING IRON AND WRAPPING WIRE FOR BEST RESULTS. FIRST WARM THE ELECTRODE ON THE CELL FOR A FEW SECONDS. THEN MELT A SMALL PUDDLE OF SOLDER ONTO THE ELECTRODE. PLACE THE EXPOSED END OF A LENGTH OF WRAPPING WIRE IN THE SOLDER AND HOLD IT IN PLACE UNTIL THE SOLDER COOLS.

PHOTOTRANSISTORS

OPTIONAL BASE LEAD

SYMBOL

THE SIMPLEST WAY TO USE A PHOTOTRANSISTOR IS TO CONNECT IT TO A SERIES RESISTOR. IT THEN FUNCTIONS AS A PHOTOCONDUCTIVE DETECTOR.

USE A LARGE VALUE (~100K TO 1M) FOR RS TO GIVE HIGH SENSITIVITY. USE A SMALL VALUE (~10K) FOR FAST SIGNALS.

+V RS PHOTOCURRENT VOUT

ALWAYS SHIELD PHOTOTRANSISTOR FROM UNWANTED LIGHT.

SIMPLE LIGHT METERS

THOUGH VERY SIMPLE, THESE LIGHT METER CIRCUITS ARE VERY SENSITIVE.

PHOTORESISTOR

R1 100K
CdS PHOTO-RESISTOR
M1 0-1 mA
9V

OK TO TRY OTHER BATTERY VOLTAGES. AVOID RAPID INCREASE IN LIGHT THAT MIGHT HARM THE METER!

SOLAR CELL

R1 1K
SOLAR CELL
M1 0-1 mA

TWO OR MORE SOLAR CELLS IN PARALLEL WILL GIVE HIGHER SENSITIVITY.

PHOTOTRANSISTOR

R1 1K
UNUSED
Q1 PHOTOTRANSISTOR
M1 0-1 mA

THE BASE-COLLECTOR JUNCTION OF Q1 FORMS A PHOTODIODE OR MINIATURE SOLAR CELL.

ULTRA-SENSITIVE LIGHT METER

.002 μF
10M
.02 μF
1M
.2 μF
100K
2.2 μF
10K
22 μF
1K
S1
KEEP BATTERY LEADS SHORT!
-9V
SOLAR CELL
741
R1 5K
R2 10K
+9V
M1 0-1 mA METER

FULL SCALE READINGS (SWITCH S1)

1 - 100 μA
2 - 10 μA
3 - 1 μA
4 - .1 μA
5 - .01 μA

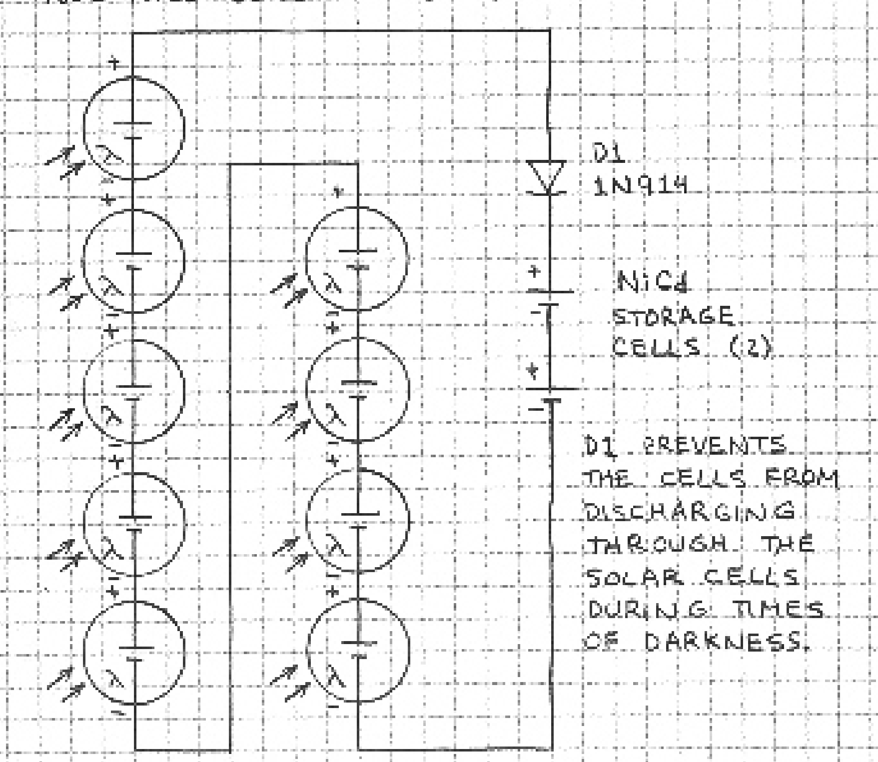
THIS CIRCUIT IS VERY SENSITIVE. ALWAYS SET SWITCH S1 TO POSITION 1 BEFORE THE CIRCUIT IS SWITCHED ON. CAREFULLY ADJUST R1 TO SET METER TO 0 WHEN THE SOLAR CELL IS TOTALLY DARK. YOU MAY HAVE TO ADJUST R2 TO PROPERLY ZERO THE METER.

CAUTION: EXCESSIVE LIGHT WILL "SLAM" THE METER'S NEEDLE.

IF ULTRA-HIGH SENSITIVITY IS NOT REQUIRED, OMIT THE UPPER RESISTORS AND USE THE LOWER TWO OR THREE.

SOLAR BATTERY CHARGER

AN ARRAY OF SOLAR CELLS WILL RECHARGE ONE OR MORE NICKEL-CADMIUM (NiCd) STORAGE CELLS. FOR EXAMPLE, NINE SOLAR CELLS CONNECTED IN SERIES WILL CHARGE TWO NiCd CELLS CONNECTED IN SERIES:

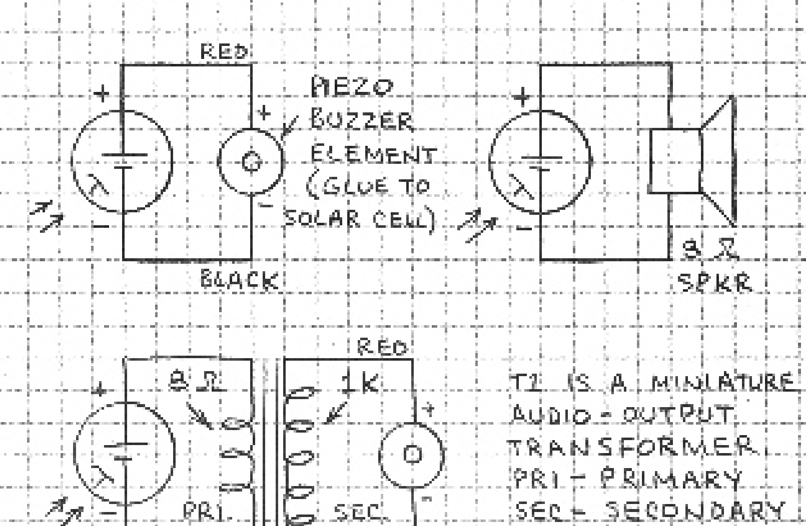


A SINGLE SILICON SOLAR CELL PRODUCES AN OPEN-CIRCUIT POTENTIAL OF FROM 0.45 TO 0.5 VOLT. A SINGLE CELL CAN PRODUCE A CURRENT OF AN AMPERE OR MORE DEPENDING ON THE AREA OF THE CELL AND THE SUNLIGHT INTENSITY. IMPORTANT: THE SOLAR CELL CURRENT MUST NOT EXCEED THE SAFE CHARGING RATE OF THE NiCd CELLS. THE OUTPUT VOLTAGE OF CELLS IN SERIES IS THE SUM OF THE CELL VOLTAGES. SOLAR CELLS ARE FRAGILE. CONNECT THEM WITH WRAPPING WIRE. MOUNT WITH SILICONE SEALANT.

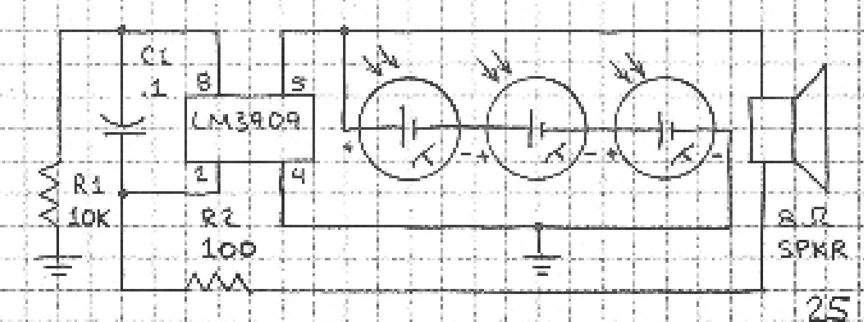
SOLAR-POWERED CIRCUITS

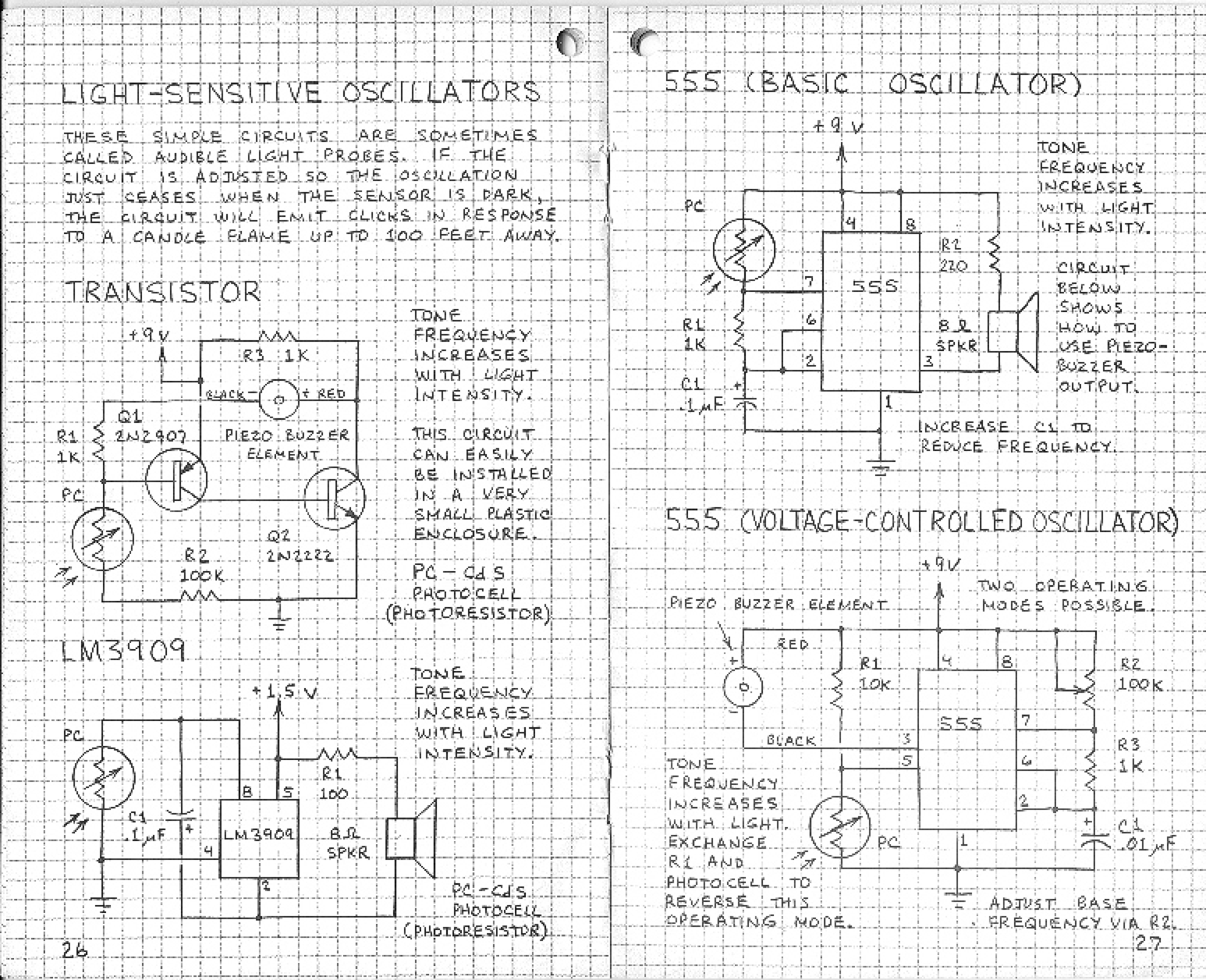
ULTRA-SIMPLE LIGHT RECEIVERS

THESE THREE RECEIVER CIRCUITS REQUIRE NO SOURCE OF POWER BEYOND THE LIGHTWAVE SIGNAL THEY RECEIVE. THEY WILL TRANSFORM AN AUDIO-FREQUENCY MODULATED LIGHT BEAM DIRECTLY INTO SOUND. THEY CAN BE USED TO CHECK INFRARED REMOTE CONTROL TRANSMITTERS AND TO RECEIVE VOICE OR TONE LIGHTWAVE SIGNALS.



SUN-POWERED OSCILLATOR





LIGHT-SENSITIVE OSCILLATORS

THESE SIMPLE CIRCUITS ARE SOMETIMES CALLED AUDIBLE LIGHT PROBES. IF THE CIRCUIT IS ADJUSTED SO THE OSCILLATION JUST CEASES WHEN THE SENSOR IS DARK, THE CIRCUIT WILL EMIT CLICKS IN RESPONSE TO A CANDLE FLAME UP TO 100 FEET AWAY.

TRANSISTOR

TONE FREQUENCY INCREASES WITH LIGHT INTENSITY.

THIS CIRCUIT CAN EASILY BE INSTALLED IN A VERY SMALL PLASTIC ENCLOSURE.

PC – CdS PHOTOCELL (PHOTORESISTOR)

LM3909

TONE FREQUENCY INCREASES WITH LIGHT INTENSITY.

PC – CdS PHOTOCELL (PHOTORESISTOR)

555 (BASIC OSCILLATOR)

TONE FREQUENCY INCREASES WITH LIGHT INTENSITY.

CIRCUIT BELOW SHOWS HOW TO USE PIEZO-BUZZER OUTPUT.

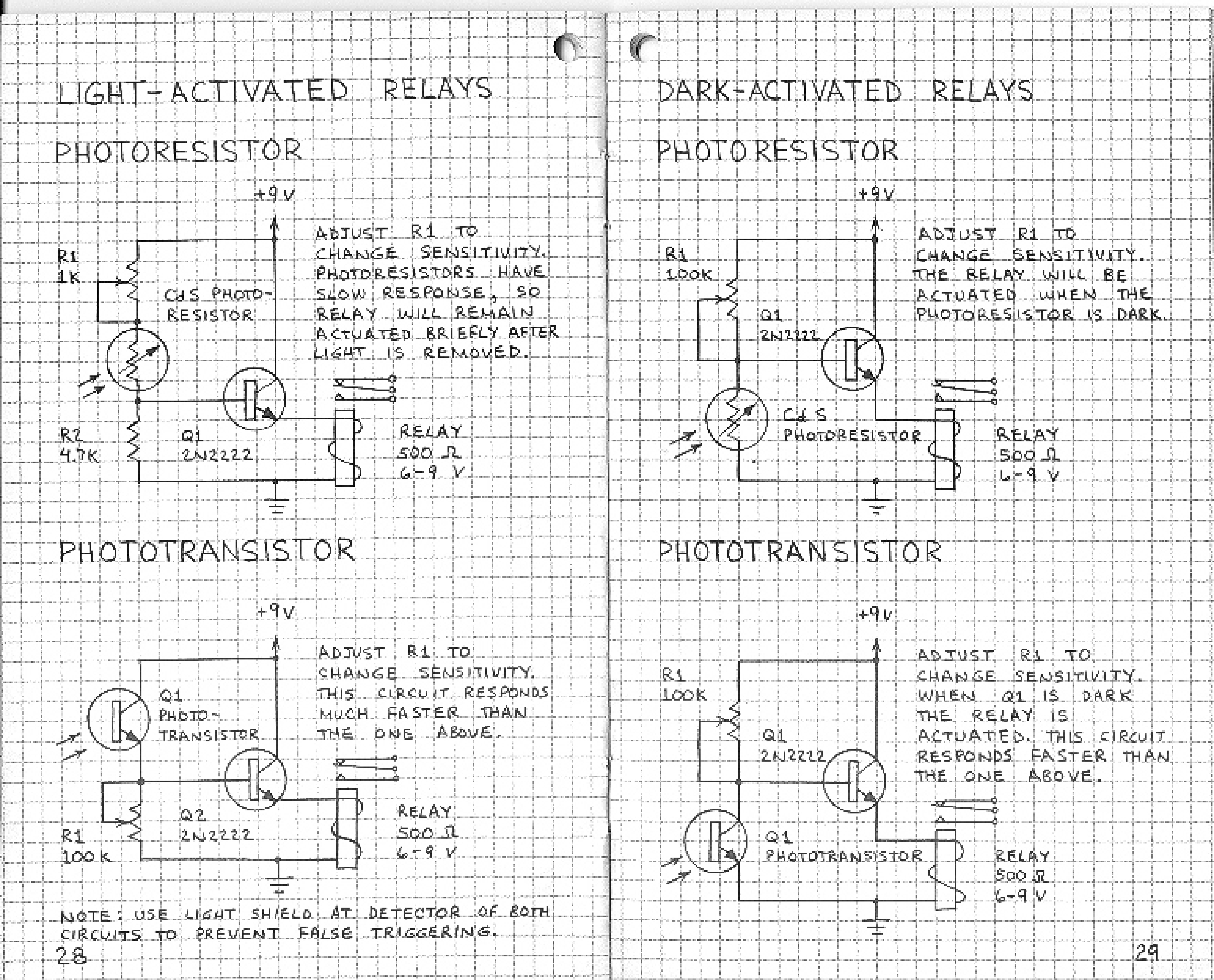
INCREASE C1 TO REDUCE FREQUENCY.

555 (VOLTAGE-CONTROLLED OSCILLATOR)

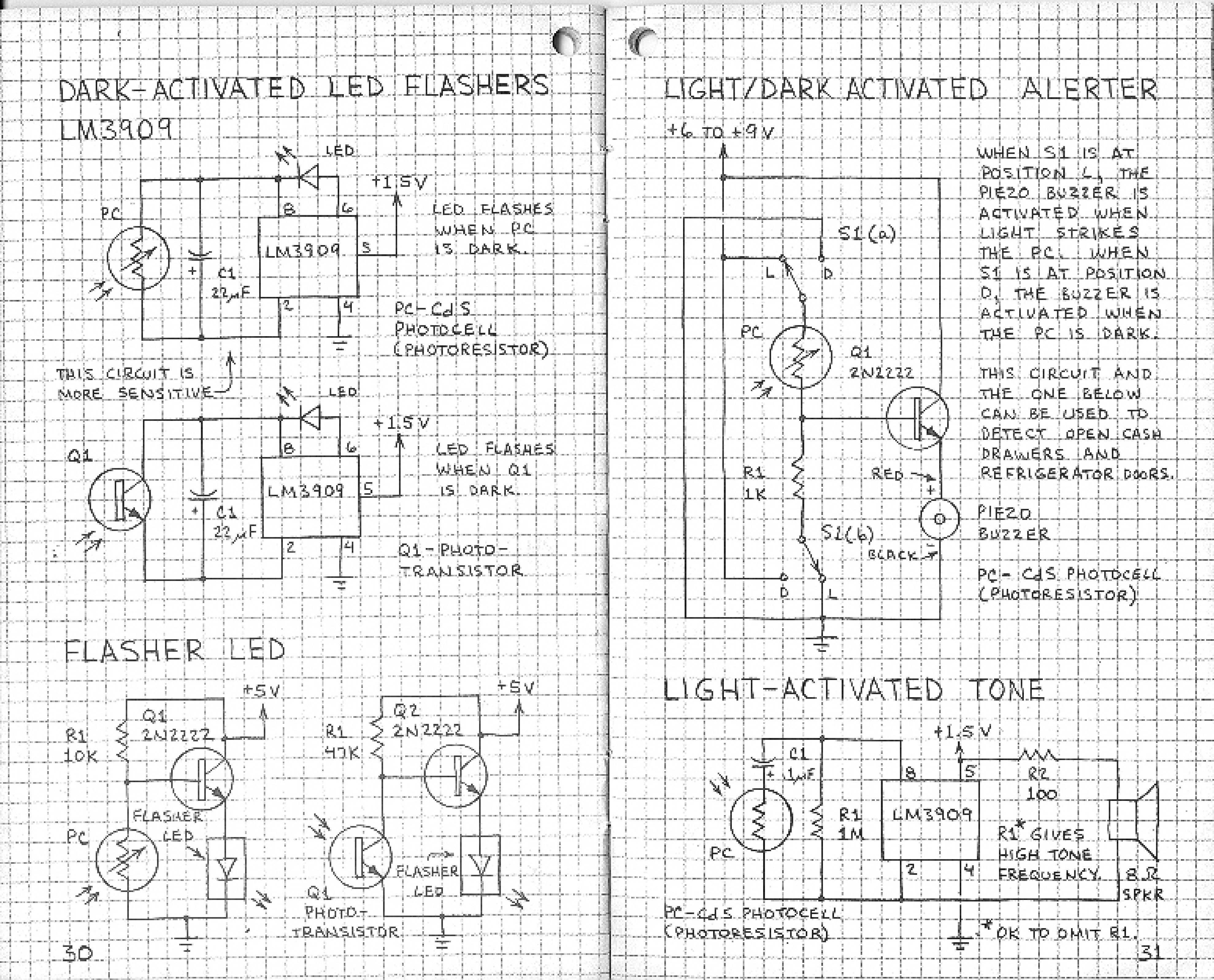
TWO OPERATING MODES POSSIBLE.

TONE FREQUENCY INCREASES WITH LIGHT. EXCHANGE R1 AND PHOTOCELL TO REVERSE THIS OPERATING MODE.

ADJUST BASE FREQUENCY VIA R2.



LIGHT-ACTIVATED RELAYS
PHOTORESISTOR
+9V
R1
1K
CdS PHOTO-
RESISTOR
R2
4.7K
Q1
2N2222
ADJUST R1 TO CHANGE SENSITIVITY. PHOTORESISTORS HAVE SLOW RESPONSE, SO RELAY WILL REMAIN ACTUATED BRIEFLY AFTER LIGHT IS REMOVED.
RELAY
500 Ω
6-9 V
PHOTOTRANSISTOR
+9V
Q1
PHOTO-
TRANSISTOR
R1
100K
Q2
2N2222
ADJUST R1 TO CHANGE SENSITIVITY. THIS CIRCUIT RESPONDS MUCH FASTER THAN THE ONE ABOVE.
RELAY
500 Ω
6-9 V
NOTE: USE LIGHT SHIELD AT DETECTOR OF BOTH CIRCUITS TO PREVENT FALSE TRIGGERING.
28
DARK-ACTIVATED RELAYS
PHOTORESISTOR
+9V
R1
100K
Q1
2N2222
CdS
PHOTORESISTOR
ADJUST R1 TO CHANGE SENSITIVITY. THE RELAY WILL BE ACTUATED WHEN THE PHOTORESISTOR IS DARK.
RELAY
500 Ω
6-9 V
PHOTOTRANSISTOR
+9V
R1
100K
Q1
2N2222
Q1
PHOTOTRANSISTOR
ADJUST R1 TO CHANGE SENSITIVITY. WHEN Q1 IS DARK THE RELAY IS ACTUATED. THIS CIRCUIT RESPONDS FASTER THAN THE ONE ABOVE.
RELAY
500 Ω
6-9 V
29


DARK-ACTIVATED LED FLASHERS
LM3909
LED
+1.5V
PC
8
6
LM3909
5
LED FLASHES WHEN PC IS DARK.
+
C1
22µF
2
4
PC- CdS PHOTOCELL (PHOTORESISTOR)
THIS CIRCUIT IS MORE SENSITIVE
LED
+1.5V
Q1
8
6
LM3909
5
LED FLASHES WHEN Q1 IS DARK.
+
C1
22µF
2
4
Q1- PHOTO-TRANSISTOR
FLASHER LED
+5V
Q1
2N2222
R1
10K
FLASHER LED
PC
+5V
Q2
2N2222
R1
47K
Q1
PHOTO-TRANSISTOR
FLASHER LED
30
LIGHT/DARK ACTIVATED ALERTER
+6 TO +9V
WHEN S1 IS AT POSITION L, THE PIEZO BUZZER IS ACTIVATED WHEN LIGHT STRIKES THE PC. WHEN S1 IS AT POSITION D, THE BUZZER IS ACTIVATED WHEN THE PC IS DARK.
S1(a)
L
D
PC
Q1
2N2222
THIS CIRCUIT AND THE ONE BELOW CAN BE USED TO DETECT OPEN CASH DRAWERS AND REFRIGERATOR DOORS.
R1
1K
RED
+
PIEZO BUZZER
S1(b)
BLACK
-
D
L
PC- CdS PHOTOCELL (PHOTORESISTOR)
LIGHT-ACTIVATED TONE
+1.5V
C1
1µF
+
8
5
R2
100
R1
1M
LM3909
R1* GIVES HIGH TONE FREQUENCY.
PC
2
4
8Ω SPKR
PC- CdS PHOTOCELL (PHOTORESISTOR)
*OK TO OMIT R1.
31

LIGHTWAVE COMMUNICATIONS

IT IS RELATIVELY EASY TO TRANSMIT VOICE OR SIGNALS BY MEANS OF VISIBLE LIGHT OR INFRARED RADIATION. THE RADIATION CAN BE SENT DIRECTLY THROUGH THE AIR OR CHANNELED THROUGH AN OPTICAL FIBER. THE INFORMATION ON THESE TWO PAGES WILL ASSIST YOU IN USING THE LIGHTWAVE COMMUNICATION CIRCUITS THAT FOLLOW.

SUITABLE COMPONENTS

SMALL INCANDESCENT LAMPS CAN BE USED TO SEND VOICE AND AUDIO-FREQUENCY SIGNALS. FOR BEST RESULTS, USE HIGH-POWER, NEAR-INFRARED-EMITTING DIODES. SUITABLE DETECTORS INCLUDE PHOTODIODES, PHOTOTRANSISTORS, AND SOLAR CELLS.

OPTICAL FIBER LINKS



USE RAZOR KNIFE TO CLEAVE THE FIBER.

PHOTOTRANSISTOR

LEDs AND DETECTORS INSTALLED IN PLASTIC RECEPTACLES LIKE THESE SIMPLIFY SHORT-RANGE FIBER LINKS. ALTERNATIVELY, CONNECT FIBER DIRECTLY TO LEDs AND DETECTORS WITH EPOXY AND HEAT-SHRINKABLE TUBING.

FREE-SPACE LINKS

BEAM DIVERGES (SPREADS)
ONLY THIS PART OF BEAM IS COLLECTED
LENS
LENS
LED
DETECTOR
RANGE (R)

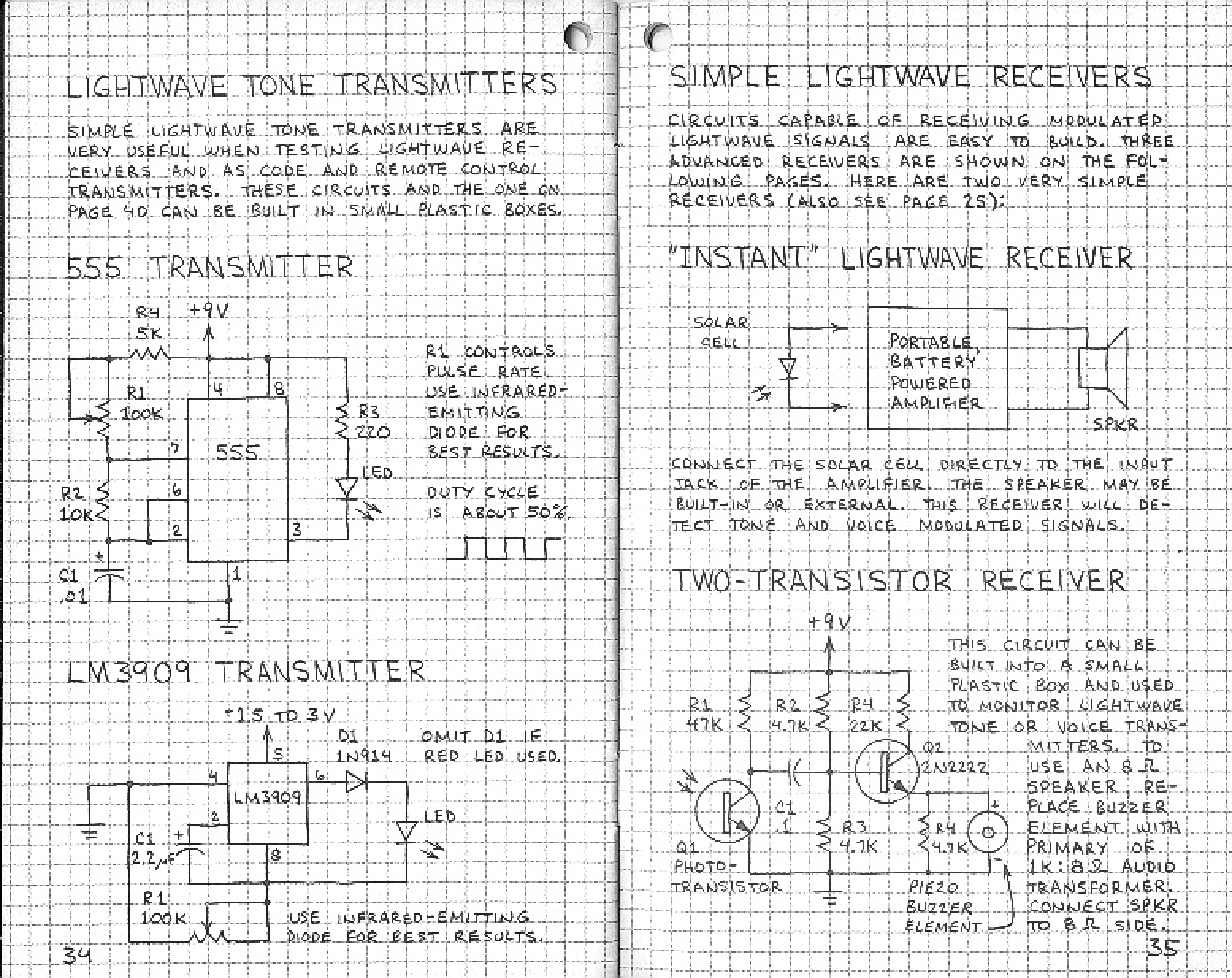
A PAIR OF LENSES WILL GREATLY INCREASE THE RANGE. USE LENSES FROM MAGNIFYING GLASS OR ORDER FROM SCIENCE SUPPLY FIRM.

FOR BEST RESULTS SHIELD DETECTOR FROM EXTERNAL LIGHT WITH HOLLOW TUBE LINED WITH BLACK PAPER OR COATED WITH FLAT BLACK PAINT. A PIECE OF DEVELOPED COLOR FILM MAKES A GOOD NEAR-INFRARED FILTER.

PRACTICE FOCUSING AN INFRARED LED BY FIRST USING A RED LED. NOTE THAT RAW BEAM FROM CLEAR ENCAPSULATED LED SHOWS BRIGHT SQUARE (THE CHIP) INSIDE DIFFUSE RED HALO. THE HALO IS NOT ELIMINATED BY AN EXTERNAL LENS.

HALO
MAIN BEAM
1
.5
0
-10 -5 0 +5 +10
BEAM DIVERGENCE (°)
TYPICAL BEAM

FOCUSING AND ALIGNING AN INFRARED FREE-SPACE LINK IS TRICKY. MOUNT THE TRANSMITTER ON A TRIPOD FOR BEST RESULTS. DOUBLING THE DIAMETER OF THE RECEIVER LENS WILL APPROXIMATELY DOUBLE THE MAXIMUM RANGE. FOR MORE DETAILS, SEE "A PRACTICAL INTRODUCTION TO LIGHTWAVE COMMUNICATIONS" (FORREST MIMS, SAMS, 1982).



LIGHTWAVE TONE TRANSMITTERS

SIMPLE LIGHTWAVE TONE TRANSMITTERS ARE VERY USEFUL WHEN TESTING LIGHTWAVE RECEIVERS AND AS CODE AND REMOTE CONTROL TRANSMITTERS. THESE CIRCUITS AND THE ONE ON PAGE 40 CAN BE BUILT IN SMALL PLASTIC BOXES.

555 TRANSMITTER

R1 CONTROLS PULSE RATE. USE INFRARED-EMITTING DIODE FOR BEST RESULTS.

DUTY CYCLE IS ABOUT 50%.

LM3909 TRANSMITTER

OMIT D1 IF RED LED USED.

USE INFRARED-EMITTING DIODE FOR BEST RESULTS.

SIMPLE LIGHTWAVE RECEIVERS

CIRCUITS CAPABLE OF RECEIVING MODULATED LIGHTWAVE SIGNALS ARE EASY TO BUILD. THREE ADVANCED RECEIVERS ARE SHOWN ON THE FOLLOWING PAGES. HERE ARE TWO VERY SIMPLE RECEIVERS (ALSO SEE PAGE 25):

"INSTANT" LIGHTWAVE RECEIVER

CONNECT THE SOLAR CELL DIRECTLY TO THE INPUT JACK OF THE AMPLIFIER. THE SPEAKER MAY BE BUILT-IN OR EXTERNAL. THIS RECEIVER WILL DETECT TONE AND VOICE MODULATED SIGNALS.

TWO-TRANSISTOR RECEIVER

THIS CIRCUIT CAN BE BUILT INTO A SMALL PLASTIC BOX AND USED TO MONITOR LIGHTWAVE TONE OR VOICE TRANSMITTERS. TO USE AN 8 Ω SPEAKER, REPLACE BUZZER ELEMENT WITH PRIMARY OF 1K:8 Ω AUDIO TRANSFORMER. CONNECT SPKR TO 8 Ω SIDE.

THE PHOTOPHONE

ON FEBRUARY 19, 1880, ALEXANDER GRAHAM BELL AND SUMNER TAINTER, PROF. BELL'S LABORATORY ASSISTANT, BECAME THE FIRST PEOPLE TO TRANSMIT THEIR VOICES OVER A BEAM OF ELECTROMAGNETIC RADIATION. BELL CALLED HIS INVENTION THE PHOTOPHONE AND SAID IT WAS FUNDAMENTALLY A GREATER INVENTION THAN THE TELEPHONE. THE PHOTOPHONE IS EASILY DUPLICATED.

PHOTOPHONE TRANSMITTER

VOICE

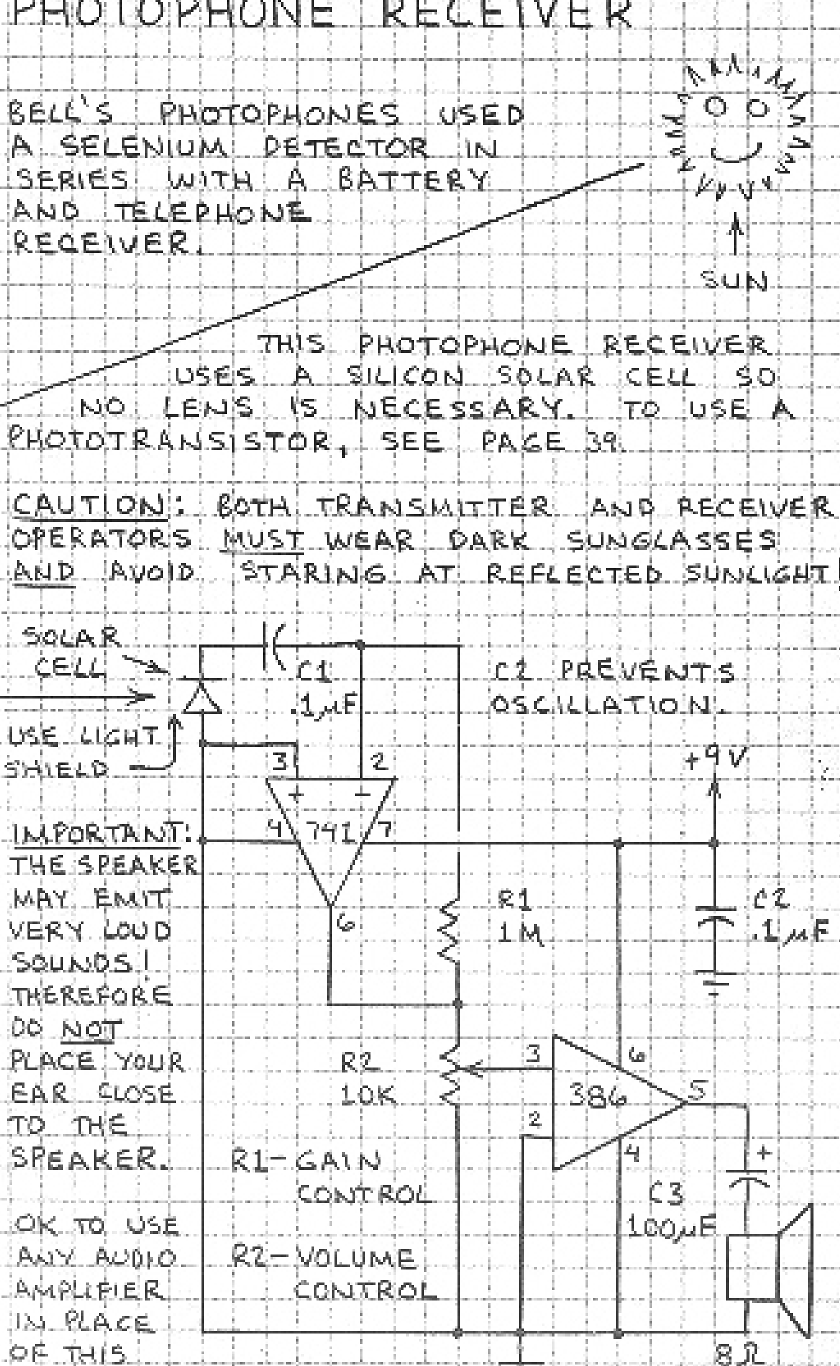
TAPE

ALUMINUM FOIL OR ALUMINIZED MYLAR (SHINY SIDE OUT)

TIN CAN OR PAPER TUBE (OPEN AT BOTH ENDS)

THE ALUMINUM FOIL OR ALUMINIZED FILM SHOULD BE STRETCHED TIGHT OVER THE CAN OR TUBE AND HELD IN PLACE WITH TAPE OR A RUBBER BAND. BE SURE THE SHINY SIDE OF THE FOIL OR FILM FACES OUTWARD. TEST THE TRANSMITTER BY REFLECTING SUNLIGHT FROM IT TO A WALL SOME DISTANCE AWAY. THE REFLECTED SUNLIGHT SHOULD FORM A DISTINCT SPOT. IF NOT, THE FOIL OR FILM IS NOT TIGHT ENOUGH. FOR BEST RESULTS, MOUNT THE TRANSMITTER ON A PHOTOGRAPHER'S TRIPOD TO SIMPLIFY AIMING THE BEAM.

PHOTOPHONE RECEIVER



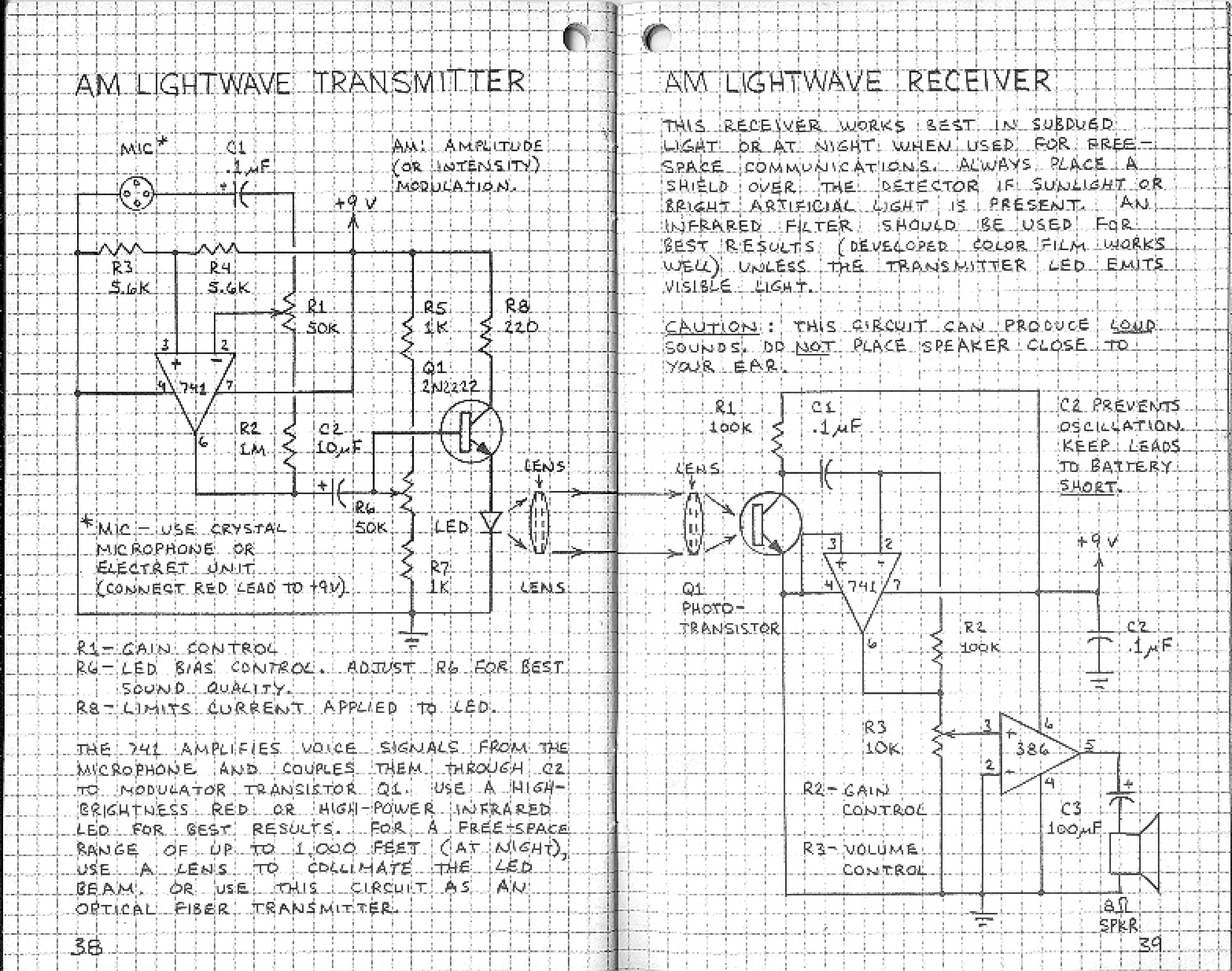
BELL'S PHOTOPHONES USED A SELENIUM DETECTOR IN SERIES WITH A BATTERY AND TELEPHONE RECEIVER.

THIS PHOTOPHONE RECEIVER USES A SILICON SOLAR CELL SO NO LENS IS NECESSARY. TO USE A PHOTOTRANSISTOR, SEE PAGE 39.

CAUTION: BOTH TRANSMITTER AND RECEIVER OPERATORS MUST WEAR DARK SUNGLASSES AND AVOID STARING AT REFLECTED SUNLIGHT!

IMPORTANT: THE SPEAKER MAY EMIT VERY LOUD SOUNDS! THEREFORE DO NOT PLACE YOUR EAR CLOSE TO THE SPEAKER.

OK TO USE ANY AUDIO AMPLIFIER IN PLACE OF THIS CIRCUIT.



AM LIGHTWAVE TRANSMITTER

AM: AMPLITUDE (OR INTENSITY) MODULATION.

*MIC – USE CRYSTAL MICROPHONE OR ELECTRET UNIT (CONNECT RED LEAD TO +9V).

R1 – GAIN CONTROL
R6 – LED BIAS CONTROL. ADJUST R6 FOR BEST SOUND QUALITY.
R8 – LIMITS CURRENT APPLIED TO LED.

THE 741 AMPLIFIES VOICE SIGNALS FROM THE MICROPHONE AND COUPLES THEM THROUGH C2 TO MODULATOR TRANSISTOR Q1. USE A HIGH-BRIGHTNESS RED OR HIGH-POWER INFRARED LED FOR BEST RESULTS. FOR A FREE-SPACE RANGE OF UP TO 1,000 FEET (AT NIGHT), USE A LENS TO COLLIMATE THE LED BEAM. OR USE THIS CIRCUIT AS AN OPTICAL FIBER TRANSMITTER.

AM LIGHTWAVE RECEIVER

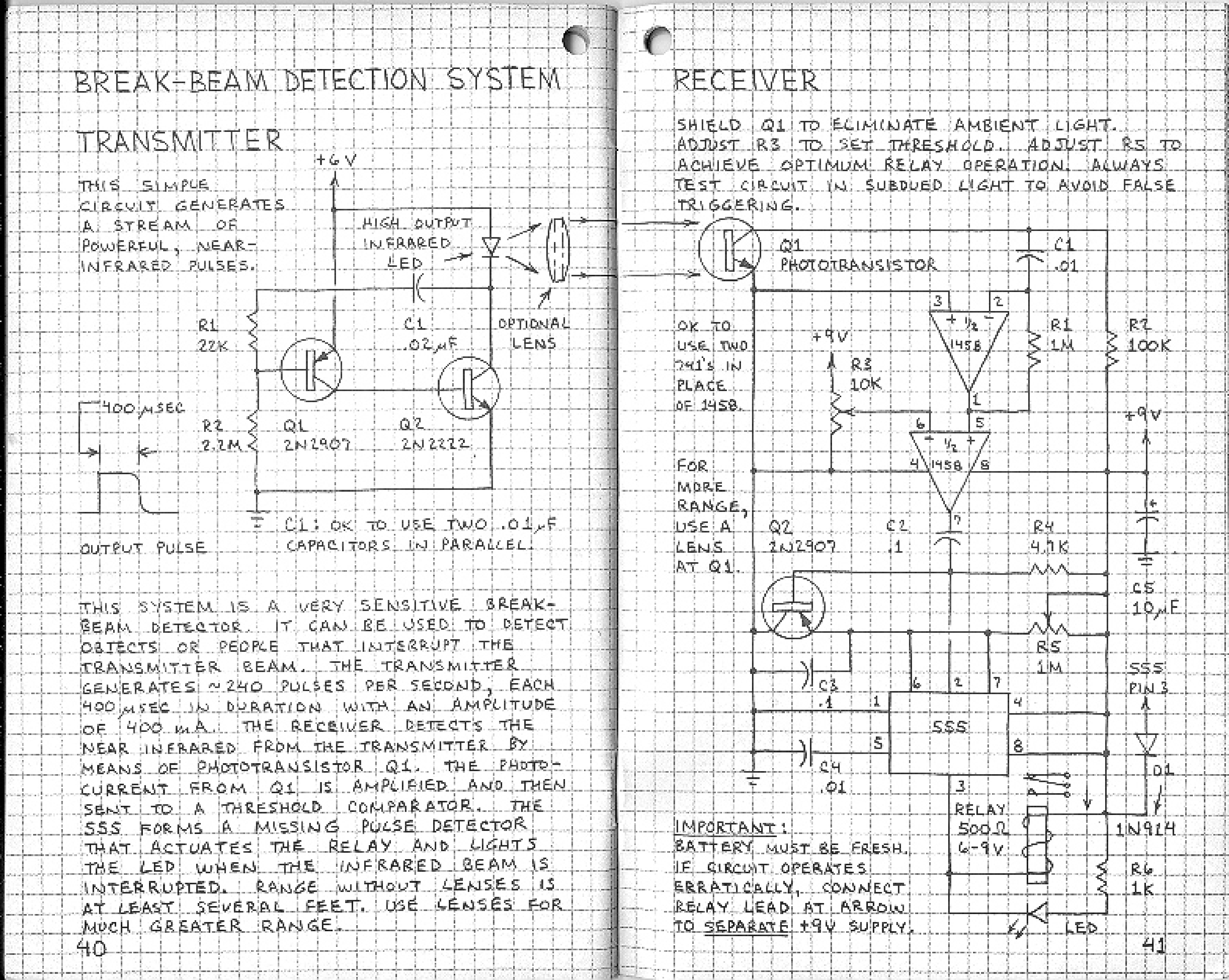
THIS RECEIVER WORKS BEST IN SUBDUED LIGHT OR AT NIGHT WHEN USED FOR FREE-SPACE COMMUNICATIONS. ALWAYS PLACE A SHIELD OVER THE DETECTOR IF SUNLIGHT OR BRIGHT ARTIFICIAL LIGHT IS PRESENT. AN INFRARED FILTER SHOULD BE USED FOR BEST RESULTS (DEVELOPED COLOR FILM WORKS WELL) UNLESS THE TRANSMITTER LED EMITS VISIBLE LIGHT.

CAUTION: THIS CIRCUIT CAN PRODUCE LOUD SOUNDS. DO NOT PLACE SPEAKER CLOSE TO YOUR EAR.

C2 PREVENTS OSCILLATION. KEEP LEADS TO BATTERY SHORT.

R2 – GAIN CONTROL

R3 – VOLUME CONTROL



BREAK-BEAM DETECTION SYSTEM

TRANSMITTER

THIS SIMPLE CIRCUIT GENERATES A STREAM OF POWERFUL, NEAR-INFRARED PULSES.

C1: OK TO USE TWO .01µF CAPACITORS IN PARALLEL.

THIS SYSTEM IS A VERY SENSITIVE BREAK-BEAM DETECTOR. IT CAN BE USED TO DETECT OBJECTS OR PEOPLE THAT INTERRUPT THE TRANSMITTER BEAM. THE TRANSMITTER GENERATES ~240 PULSES PER SECOND, EACH 400µSEC IN DURATION WITH AN AMPLITUDE OF 400 mA. THE RECEIVER DETECTS THE NEAR INFRARED FROM THE TRANSMITTER BY MEANS OF PHOTOTRANSISTOR Q1. THE PHOTOCURRENT FROM Q1 IS AMPLIFIED AND THEN SENT TO A THRESHOLD COMPARATOR. THE 555 FORMS A MISSING PULSE DETECTOR THAT ACTUATES THE RELAY AND LIGHTS THE LED WHEN THE INFRARED BEAM IS INTERRUPTED. RANGE WITHOUT LENSES IS AT LEAST SEVERAL FEET. USE LENSES FOR MUCH GREATER RANGE.

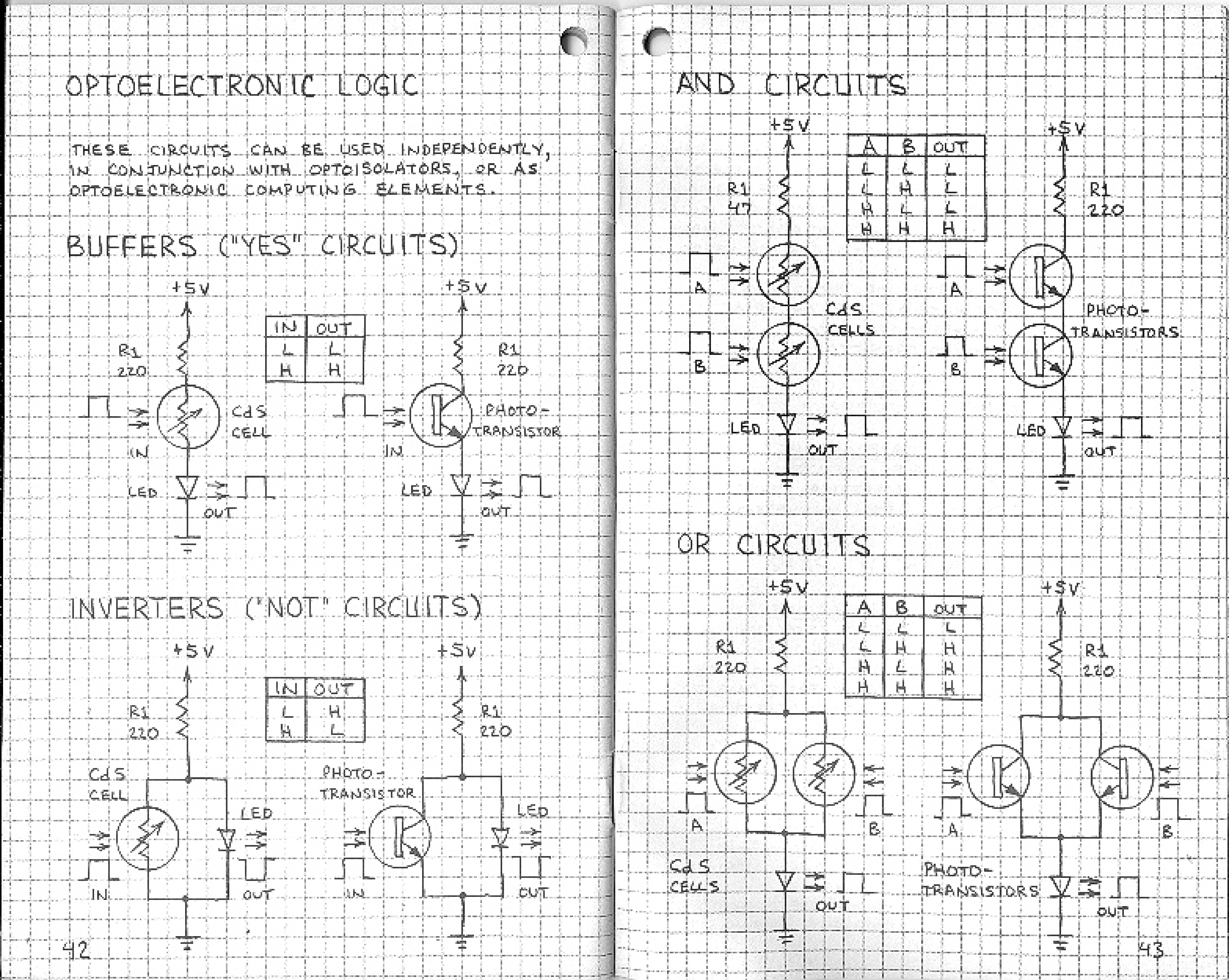
RECEIVER

SHIELD Q1 TO ELIMINATE AMBIENT LIGHT. ADJUST R3 TO SET THRESHOLD. ADJUST R5 TO ACHIEVE OPTIMUM RELAY OPERATION. ALWAYS TEST CIRCUIT IN SUBDUED LIGHT TO AVOID FALSE TRIGGERING.

OK TO USE TWO 741's IN PLACE OF 1458.

FOR MORE RANGE, USE A LENS AT Q1.

IMPORTANT: BATTERY MUST BE FRESH. IF CIRCUIT OPERATES ERRATICALLY, CONNECT RELAY LEAD AT ARROW TO SEPARATE +9V SUPPLY.



OPTOELECTRONIC LOGIC

THESE CIRCUITS CAN BE USED INDEPENDENTLY, IN CONJUNCTION WITH OPTOISOLATORS, OR AS OPTOELECTRONIC COMPUTING ELEMENTS.

BUFFERS ("YES" CIRCUITS)

IN	OUT
L	L
H	H

INVERTERS ("NOT" CIRCUITS)

IN	OUT
L	H
H	L

AND CIRCUITS

A	B	OUT
L	L	L
L	H	L
H	L	L
H	H	H

OR CIRCUITS

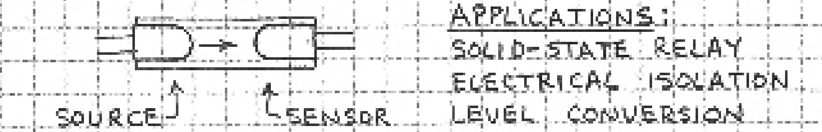
A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	H

SOURCE / SENSOR PAIRS

SOURCE/SENSOR PAIRS ARE ALSO CALLED OPTO-ISOLATORS, OPTOCOUPLERS, PHOTO-ISOLATED COUPLERS, AND PHOTON ISOLATORS. THEY HAVE MANY IMPORTANT APPLICATIONS IN ELECTRONICS. THEY ARE PARTICULARLY IMPORTANT AT PROVIDING ELECTRICAL ISOLATION BETWEEN TWO SEPARATE CIRCUITS. MANY SOURCE-SENSOR COMBINATIONS CAN BE USED:

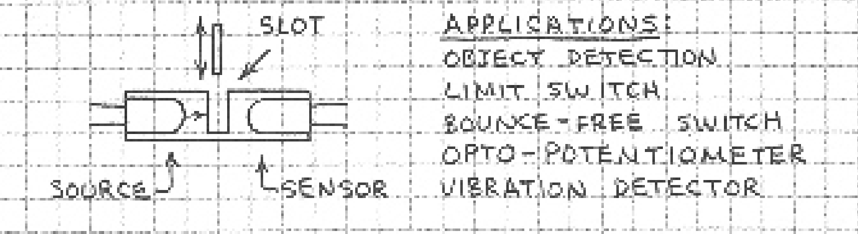
LED → PHOTOTRANSISTOR OR PHOTODIODE
LED → LIGHT-ACTIVATED SCR OR TRIAC
TUNGSTEN LAMP → PHOTORESISTOR
NEON LAMP → PHOTORESISTOR

CLOSED PAIR



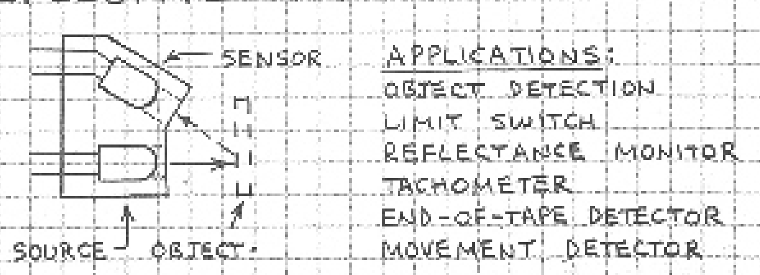
APPLICATIONS:
SOLID-STATE RELAY
ELECTRICAL ISOLATION
LEVEL CONVERSION

TRANSMISSION/SLOT PAIR



APPLICATIONS:
OBJECT DETECTION
LIMIT SWITCH
BOUNCE-FREE SWITCH
OPTO-POTENTIOMETER
VIBRATION DETECTOR

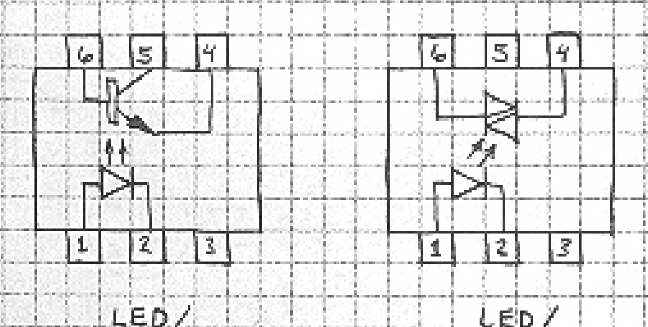
REFLECTIVE PAIR



APPLICATIONS:
OBJECT DETECTION
LIMIT SWITCH
REFLECTANCE MONITOR
TACHOMETER
END-OF-TAPE DETECTOR
MOVEMENT DETECTOR

INTEGRATED SOURCE/SENSORS

MANY KINDS OF SOURCE/SENSOR PAIRS ARE AVAILABLE IN MINIATURE INTEGRATED CIRCUIT PACKAGES. HERE ARE TWO TYPICAL EXAMPLES:



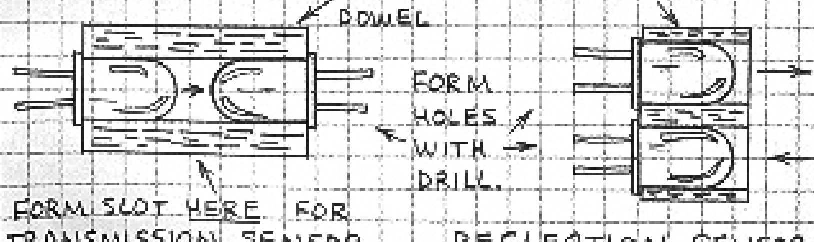
LED/ PHOTOTRANSISTOR   LED/ LIGHT-ACTIVATED TRIAC

DO-IT-YOURSELF SOURCE/SENSORS

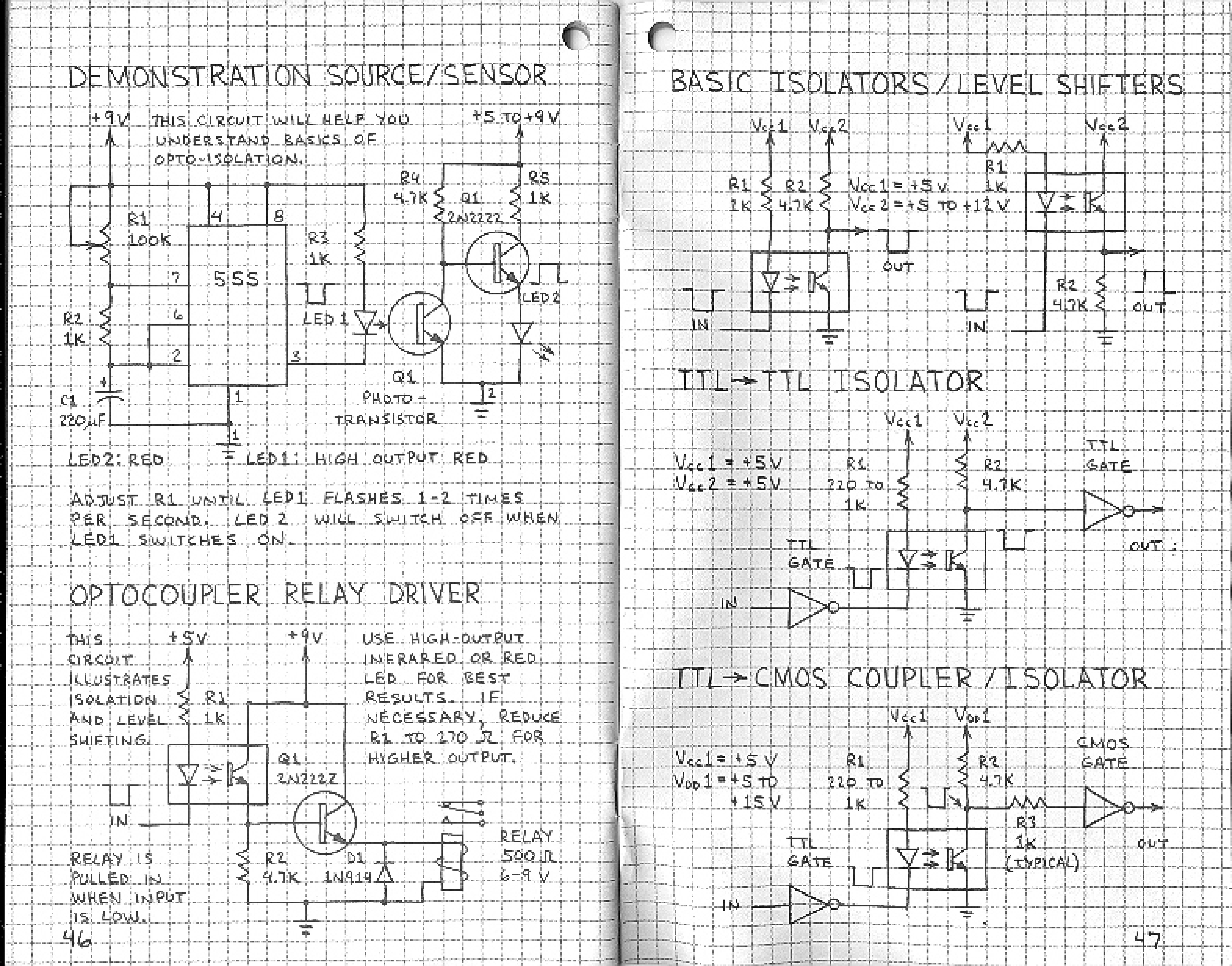
SOURCE/SENSOR PAIRS CAN BE EASILY MADE FROM INDIVIDUAL COMPONENTS. FOR EXAMPLE, HERE IS A SIMPLE LED-PHOTOTRANSISTOR PAIR:

HEAT-SHRINK TUBING
LED
PHOTO-TRANSISTOR

THE SOURCE AND SENSOR CAN BE INSTALLED IN WOOD OR PLASTIC STOCK. HERE ARE TWO OF MANY POSSIBILITIES:



REFLECTION SENSOR


DEMONSTRATION SOURCE/SENSOR
THIS CIRCUIT WILL HELP YOU UNDERSTAND BASICS OF OPTO-ISOLATION.
+9V
+5 TO +9V
R1 100K
R2 1K
C1 220µF
555
R3 1K
LED 1
Q1 PHOTO-TRANSISTOR
R4 4.7K
Q1 2N2222
R5 1K
LED2
LED2: RED
LED1: HIGH OUTPUT RED
ADJUST R1 UNTIL LED1 FLASHES 1-2 TIMES PER SECOND. LED 2 WILL SWITCH OFF WHEN LED1 SWITCHES ON.
OPTOCOUPLER RELAY DRIVER
THIS CIRCUIT ILLUSTRATES ISOLATION AND LEVEL SHIFTING.
+5V
+9V
R1 1K
IN
Q1 2N2222
R2 4.7K
D1 1N914
USE HIGH-OUTPUT INFRARED OR RED LED FOR BEST RESULTS. IF NECESSARY, REDUCE R1 TO 270 Ω FOR HIGHER OUTPUT.
RELAY 500 Ω 6-9 V
RELAY IS PULLED IN WHEN INPUT IS LOW.
46
BASIC ISOLATORS / LEVEL SHIFTERS
Vcc1
Vcc2
R1 1K
R2 4.7K
Vcc1 = +5 V
Vcc2 = +5 TO +12 V
IN
OUT
R1 1K
R2 4.7K
TTL → TTL ISOLATOR
Vcc1 = +5V
Vcc2 = +5V
R1 220 TO 1K
R2 4.7K
TTL GATE
IN
OUT
TTL → CMOS COUPLER / ISOLATOR
Vcc1
VDD1
Vcc1 = +5 V
VDD1 = +5 TO +15 V
R1 220 TO 1K
R2 4.7K
R3 1K (TYPICAL)
CMOS GATE
TTL GATE
IN
OUT
47

OPTOCOUPLER PLUS BOOSTER

INVERTED OUTPUT

$V_{cc}1$ = +5V
$V_{cc}2$ = +5 TO +12V

$V_{cc}1$ $V_{cc}2$ $V_{cc}2$
R1 220 TO 1K
R2 4.7K
R3 4.7K
Q1 2N2222
IN
OUT

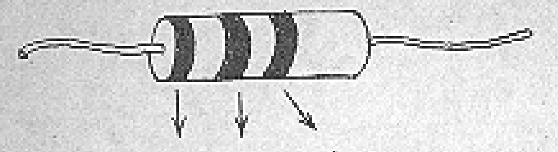
NON-INVERTED OUTPUT

$V_{cc}1$ = +5V
$V_{cc}2$ = +5 TO +12V

$V_{cc}1$ $V_{cc}2$
R1 220 TO 1K
R2 4.7K
Q1 2N2222
R3 4.7K
IN
OUT

THE BOOSTER TRANSISTOR (Q1) IN THESE CIRCUITS PROVIDES MORE POWER-HANDLING CAPABILITY THAN THE PHOTOTRANSISTORS IN MOST COMMERCIAL OPTOCOUPLERS. R3 CAN BE REPLACED BY A LOAD SUCH AS A RELAY.

RESISTOR COLOR CODE



BLACK	0	0	× 1
BROWN	1	1	× 10
RED	2	2	× 100
ORANGE	3	3	× 1,000
YELLOW	4	4	× 10,000
GREEN	5	5	× 100,000
BLUE	6	6	× 1,000,000
VIOLET	7	7	× 10,000,000
GRAY	8	8	× 100,000,000
WHITE	9	9	—

FOURTH BAND INDICATES TOLERANCE (ACCURACY):
GOLD = ±5%   SILVER = ±10%   NONE = ±20%

OHM'S LAW:

$V = IR$ $R = V/I$
$I = V/R$ $P = VI = I^2R$

ABBREVIATIONS

A = AMPERE	R = RESISTANCE
F = FARAD	V = VOLT
I = CURRENT	W = WATT
P = POWER	Ω = OHM

M (MEG-) = × 1,000,000
K (KILO-) = × 1,000
m (MILLI-) = .001
μ (MICRO-) = .000 001
n (NANO-) = .000 000 001
p (PICO-) = .000 000 000 001